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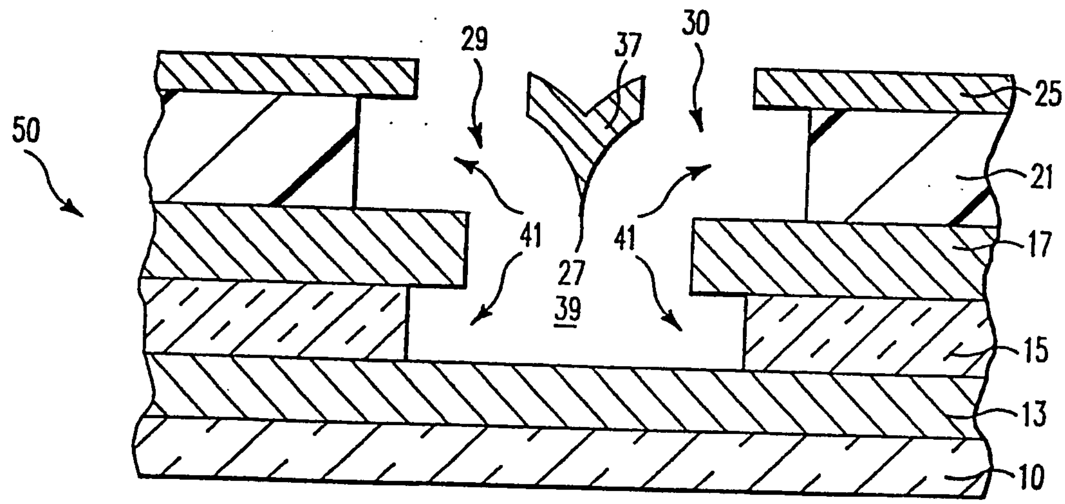

(57) Abstract

The present invention relates generally to a new integrated Vacuum Microelectronic Device (VMD) and a method for making the same. Vacuum Microelectronic Devices require several unique three dimensional structures: a sharp field emission tip, accurate alignment of the tip inside a control grid structure in a vacuum environment, and an anode to collect electrons emitted by the tip. Also disclosed is a new structure and a process for forming diodes, triodes, tetrodes, pentodes and other similar structures. The final structure made can also be connected to other similar VMD devices or to other electronic devices.

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PROCESS AND STRUCTURE OF AN INTEGRATED VACUUM MICROELECTRONIC DEVICE

FIELD OF THE INVENTION

The present invention relates generally to a new integrated Vacuum Microelectronic Device (VMD) and a method for making the same. Vacuum Microelectronic Devices require several unique three dimensional structures: a sharp field emission tip, accurate alignment of the tip inside a control grid structure in preferably a vacuum environment, and an anode to collect electrons emitted by the tip.

CROSS-REFERENCE

This patent application relates to U. S. Patent Application Serial No. ________, IBM Attorney Docket No. FI9-90-023, filed concurrently on July ___, 1990, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The designers of electronic systems have for many years thought of ways to design and improve semiconductor devices. The vacuum tube, once the mainstay of electronics, had limitations such as the mechanically fabricated structures inside the glass

envelope preventing miniaturization and integration, and the thermionic cathode keeping the power drain high. There have recently been significant developments in this area that offer the opportunity of escaping the previous restraints. Semiconductor fabrication techniques can now be used to develop structures in microminiature form and integrate many of them together. Combining these microminiature structures with a field emission electron source one can now produce microminiature vacuum tube structures which do not require heated cathodes. These structures being on the order of micrometers in size, permit the integration of many devices on a single substrate, just as many semiconductor devices are produced on a single chip.

The Vacuum Microelectronic Devices presently in use require several unique three-dimensional structures, which include, a vacuum space, a sharp, preferably less than 100 nm radius field emission tip, and the accurate alignment of tip inside an extraction/control electrode structure. Vacuum Microelectronic Devices include a field-emission cathode and add additional structures, such as, an extension of the vacuum space, an anode opposite the cathode tip, and there may or may not be additional accurately aligned control electrodes placed between the tip and the anode.

The field emission display elements that utilize these Vacuum Microelectronic Devices use the basic field emission structure and add additional structures, such as, an extension of the vacuum space, a phosphor surface opposite the cathode tip, and additional electrodes to collect and/or control the electron current. Groups of individual Vacuum Microelectronic Devices and/or display elements can

be electrically interconnected during fabrication to form integrated circuits and/or displays.

Vacuum Microelectronic Devices have several unique features. They are expected to have sub pico second switching speeds and are thought by some to be the fastest electronic devices possible. They will operate at temperatures ranging from near absolute zero to hundreds of degrees Celsius limited principally by their materials of construction. These structures can be made of almost any conductor and insulator material. They are intrinsically radiation hard. They are also very efficient because control is by charge and not by current flow, and the use of high field emitters eliminates the thermionic emission heaters of traditional vacuum devices.

In U. S. Patent No. 4,721,885, and also in an article published by Ivor Brodie, "Physical Considerations in Vacuum Microelectronics Devices", IEEE Transactions on Electron Devices, Vol. 36, No. 11, pages 2641-2644 (November 1989), a field-emission microtriode is described. The triode consists of a metal cone attached to a metal or high-conductivity semiconductor base electrode. The height of the cone is given as "h", the radius of curvature at the cathode tip is "r". A metal anode is held at a distance "d" from the tip of the cone by a second insulating layer. The cone tip is at the center of a circular hole having a radius "a", in a gate (or first anode) electrode of thickness "t". When the appropriate positive potential difference is applied between the base electrode and the gate electrode, an electric field is generated at the cathode tip that allows electrons to tunnel through the tip into the vacuum space and move towards the anode. The field

at the tip and, hence, the quantity of electrons emitted can be controlled by varying the gate potential.

While these Vacuum Microelectronic Devices can be made in almost any size and may have applications as discrete devices, their best performance and major application is expected to come from extreme miniaturization, large arrays, and complex very large scale integration of circuits.

Non-thermionic field emitters, field emission devices, and field emission displays are all known in the art. Since the fabrication of the field emission cathode structure is a critical element common to the devices mentioned, its art will be addressed first. The material (insulators and conductors/field emitters) are all deposited and processed by relatively common deposition and lithographic processing techniques with the single exception of a special sharp edge (blade) or point (tip) structure which is common to all field-emission cathodes. The art can be broadly classified into five categories, and these categories are primarily categorized by the methods used to form this sharp blade or tip.

The first category is one of the earliest categories in which the cathode tip structure is formed by the direct deposition of the material. An example of this type is exemplified in a paper by C. A. Spindt, "A Thin-Film Field-Emission Cathode", J. Appl. Phys., Vol. 39, No. 7, pages 3504-3505 (1968), in which sharp molybdenum cone-shaped emitters are formed inside holes in a molybdenum anode layer and on a molybdenum cathode layer. The two layers are separated by an insulating layer which has been etched away in the areas of the holes in the anode layer down to the cathode layer. The cones are

formed by simultaneous normal and steep angle depositions of the molybdenum and alumina, respectively, onto the rotating substrate containing the anode and cathode layers. The newly deposited alumina is selectively removed. Similar work has also been disclosed in U. S. Patent No. 3,755,704.

A second category is the use of orientation-dependent etching of single crystal materials such as silicon. The principle of the orientation-dependent etching is to preferentially attack a particular crystallographic face of a material. By using single crystal materials patterned with a masking material, the anisotropically etched areas will be bounded by the slow etching faces which intersect at well defined edges and points of the material's basic crystallographic shape. A suitable combination of etch, material, and orientation can result in very sharply defined points that can be used as field emitters. U. S. Patent No. 3,665,241 issued to Spindt, et al., is an example of this method in which an etch mask of one or more islands is placed over a single-crystal material which is then etched using an etchant which attacks some of the crystallographic planes of the material faster than the others creating etch profiles bounded by the slow etching planes (an orientation-dependent etch). As the slow etching planes converge under the center of the mask, multifaceted geometric forms with sharp edges and points are formed whose shape is determined by the etchant, orientation of the crystal, and shape of the mask. Orientation-dependent anisotropic etching while an established method to create the tips can also have an adverse effect by making these sharp tips blunt (or reducing the radius of the cathode

tip), thus reducing their effectiveness as field emitters, as discussed by Cade, N. A. et al., "Wet Etching of Cusp Structures for Field-Emission Devices," IEEE Transactions on Electron Devices, Vol. 36, No. 11, pages 2709-2714 (November 1989).

A third category uses isotropic etches to form the structure. Isotropic etches etch uniformly in all directions. When masked, the mask edge becomes the center point of an arc which outlines the classic isotropic etch profile under the masking material. The radius of the arc is equal to the etch depth. Etching around an isolated masked island allows the etch profile to converge on the center of the mask leaving a sharp tip of the unetched material which can be used as a field emitter. An example of this is exemplified in U. S. Patent No. 3,998,678, issued to Shigeo Fukase, et al. An emitter material is masked using islands of a lithographically formed and etch resistant material. The emitter material is etched with an isotropic etchant which forms an isotropic etch profile (circular vertical profile with a radius extending under the resist from the edge). When the etch profile converges under the center of the mask from all sides, a sharp point or tip results.

A fourth category uses oxidation processes to form the Vacuum Microelectronic Device. Oxidation processes form a tip by oxidizing the emitter material. Oxidation profiles under oxidation masks are virtually identical to isotropic etch profiles under masks and form the same tip structure as the profiles converge under a circular mask. When the oxidized material is removed the unoxidized tip can function as a field emitter. U. S. Patent No. 3,970,887 issued to Smith et al. exemplifies this process. A substrate of electron emission material

such as silicon is used. A thermally grown oxide layer is grown on the substrate and is then lithographically featured and etched to result in one or more islands of silicon dioxide. The substrate is then reoxidized during which the islands of previously formed oxide act to significantly retard the oxidation of the silicon under them. The resulting oxidation profile is very similar to the isotropic etch profile and similarly converges under the islands leaving a sharp point profile in the silicon which can be exposed by removing the oxide. Other masking material such as silicon nitride can be used to similarly retard the oxidation and produce the desired sharp tip profile.

A fifth category etches a pit which is the inverse of the desired sharply pointed shape in an expendable material which is used as a mold for the emitter material and then removed by etching. U. S. Patent No. 4,307,507 issued to Gray et al exemplifies a limited embodiment of this technique. Holes in a masking material are lithographically formed on a single crystal silicon substrate. The substrate is orientation-dependent etched through the mask holes forming etch pits with the inverse of the desired pointed shape. The mask is removed and a layer of emission material is deposited over the surface filling the pits. The silicon of the mold is then etched away freeing the pointed replicas of the pits whose sharp points can be used as field emitters.

All of the emitter formation techniques mentioned above have several limitations. Orientation-dependent etching requires the use of a substrate of single crystal emitter material. Most all of them require the substrate to be made of or coated with the emitter material. Most all of them

form the emitter first which complicates the fabrication of the subsequent electrode layers and the vacuum space needed for a fully functional Vacuum Microelectronic Device.

Sometimes the method used or the particular processing regime does not produce field emission tips of sufficiently small radius. The art includes some methods by which the tip can be sharpened to further reduce this radius. In a paper by Campisi et al, "Microfabrication Of Field Emission Devices For Vacuum Integrated Circuits Using Orientation Dependent Etching", Mat. Res. Soc. Symp. Proc., Vol. 76, pages 67-72 (1987), reports the sharpening of silicon tips by slowly etching them in an isotropic etch. Another paper entitled "A Progress Report On The Livermore Miniature Vacuum Tube Project", by W. J. Orvis et al, IEDM 89, pages 529-531 (1989), reports the sharpening of silicon tips by thermally oxidizing them and then etching away the oxide. U. S. Patent No. 3,921,022, also discloses a novel method of providing multiple tips or tiplets at the tip of a conical or pyramidical shaped field emitter.

Various processes creating two or three electrode VMD structures been reported in the art. As an example a paper entitled "A Progress Report On The Livermore Miniature Vacuum Tube Project", by Orvis et al, IEDM, pages 529-531 (1989), describes a process in which silicon emitters formed by either orientation-dependent or isotropic etching are used. Lithographically featured doped polysilicon anode and grid layers are separated from the emitter and each other by layers of low density glass.

It is now possible as exemplified in Busta, H. H. et al. "Field Emission from Tungsten-Clad Silicon Pyramids", IEEE Transactions on Electron Devices,

Vol. 36, No. 11, pages 2679-2685 (November 1989), to use coating or cladding on these cathode tips or pyramids to enhance or modify the cathode tip properties.

In this developing field of Vacuum Microelectronic Devices the art has also started to show how these field emission cathodes and extraction electrodes can be used in a practical application, such as, in a display applications. U. S. Patent No. 4,857,799 issued to Spindt et al illustrates how a substrate containing field emitters and extraction electrodes can be joined to a separate transparent window which contains anode conductors and phosphor strips, all of which can work in concert to form a color display. Another color display device using vacuum microelectronic type structure was patented in U. S. Patent No. 3,855,499.

This patent application also discloses an etch process which can significantly reduce the unwanted undercut for a Vacuum Microelectronic Device while still allowing the formation of bridge structures.

In summary a typical field emission Vacuum Microelectronic Devices are made up of a sharply pointed cathode, surrounded by a control and/or extraction electrode, and pointing toward an anode surface. The cathode tip could have a point or a blade profile. One of the key technologies in fabricating these devices is the formation of the sharp field emission (cathode) tip which has preferably a radius on the order of 10 - 100 nm. The most common methods of formation include orientation-dependent etching, isotropic etching, and thermal oxidation.

SUMMARY AND OBJECTS OF THE INVENTION

In one aspect this invention discloses a process of making at least one integrated vacuum microelectronic device comprising the steps of:

a) providing at least one hole in a substrate having at least one electrically conductive material,

b) filling at least a portion of the hole with at least one material sufficiently to form a cusp,

c) depositing at least one layer of a material which is capable of emitting electrons under the influence of an electrical field, and filling at least a portion of the cusp to form a tip,

d) providing at least one access hole to help facilitate the removal of material underneath the cusp, and

e) removing the material underneath the cusp to expose at least a portion of the tip of the electron-emitting material and at least a portion of the electrically conductive material in the substrate, thereby forming at least one integrated vacuum microelectronic device.

In another aspect this invention discloses a process of making at least one integrated vacuum microelectronic device comprising the steps of:

a) providing at least one hole in a substrate,

b) depositing at least one insulative material and filling the hole to form a cusp,

c) depositing at least one layer of a material which is capable of emitting electrons under the influence of an electrical field, and filling at least a portion of the cusp to form a tip,

d) providing at least one access hole to help facilitate the removal of material underneath the

cusp, and

e) through the access hole removing all of the material in the hole and exposing at least a portion of the tip of the electron-emitting material and at least a portion of the electrically conductive material in the substrate, thereby forming at least one integrated vacuum microelectronic device.

Still another aspect of this invention discloses an integrated vacuum microelectronic device comprising an electron-emitting material having a field emission tip and at least one access hole that leads into a chamber, wherein the field emitter tip face an anode which is in the chamber and separated by at least one material.

The integrated vacuum microelectronic device of this invention could also have at least one emitter tip which is electrically isolated from another tip or at least one tip could be electrically connected to another electronic component. Similarly, the anode could be a part of an electronic display device or the device itself could be a used in an electronic display device.

A product can also be made by any of the processes of this invention.

One object of this disclosure is to fabricate one or more Vacuum Microelectronic Devices, consisting of a field emitter tip aligned inside a control electrode (gate) and diametrically opposed to a electron collection electrode (anode).

Another object is to modify the basic process to create simpler diode structures which function without gate structures.

Still another object is to add additional gate structures to form more complex devices such as, for

example, tetrodes (two gates), pentodes (three gates), to name a few.

Yet another object is to limit the nonproductive undercut of this process by employing a novel two step etching sequence.

Still yet another object of this invention is to interconnect at least one of the VMD device into integrated circuits.

Yet another object of this invention is to interconnect at least one of the VMD device to another electronic device.

The objects of the present invention can be achieved using a novel fabrication process in which the conformal deposition of an insulator into a hole produces a symmetric cusp that can be used as a mold to form a pointed or sharp field emission tip. Since it is only the physical hole that allows the cusp to form, the hole can be created out of any stable material including layered alternating stacks of conductors and insulators which can act as the electrodes of the finished device. Two electrodes (anode and emitter) form a simple diode while three, four, and five electrodes would form respectively a triode, tetrode, and pentode for example. Further, since the cusp is self aligned within the center of the hole it is also aligned to the center of these electrodes. The basic device structure is completed by filling the cusp with a material capable of emitting electrons under the influence of an electric field or an electron-emitting material. Access holes created in the electron-emitting material allow the removal of the insulator of the cusp forming layer from the hole and from underneath the emitter material, thus forming a space and freeing the sharp tip of the emitter (field emission cathode) that was

molded by the cusp.

The process is not limited to any particular set of emitter, conductor, or insulator materials. Many different materials and material combinations can easily be used with this process.

The removal of the cusp insulator material to produce a clean emitter tip, results in the removal of material from under the emitter to free the tip, requiring the use of for example an isotropic etch. Exclusive use of isotropic etching would produce excessive nonproductive undercut. This nonproductive undercut only serves to weaken the structure and occupy unnecessary space. To eliminate this limitation a novel two step etch process is used to minimize this nonproductive undercut. In this process, two access holes, one on each side of the emitter bridge that spans the vacuum space are made. These access holes intentionally overlap the vacuum space hole. These access holes further allow the cusp insulator etchants to empty the vacuum space. A reactive ion etch (RIE) is used to selectively etch the insulator all the way to the bottom of the vacuum space hole without undercut. A selective isotropic etch (wet or plasma) is then used to remove the insulator partition from under the bridge, thus freeing the emitter tip and creating the opening for the vacuum space or forming a chamber. The resulting undercut on other exposed insulator edges is limited to an amount equal to half the partition thickness because it is being etched from both sides.

Since the electrodes are made of simple conductors, device interconnection can be accomplished using the same layers and vertically through vias in the insulators. This eliminates the extra wiring layers and greatly simplifies overall

fabrication, turnaround time, and device area by reducing the average number of device contact openings.

Passive devices are also easily made. For example, capacitors can be made across the normal insulating layers even allowing vertical coupling of layers capacitively (e.g. one device's plate to another's grid level) and can also be integrated in substrate using trench techniques. The use of metal oxides is a good example of resistor elements and it, too, may be done between vertical conductor levels or as separate elements.

Additional advantages and features will become apparent as the subject invention becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the invention believed to be novel and the elements characteristic of the invention are set forth with particularity in the appended claims. The drawings are for illustration only and are not drawn to scale. The invention itself, however, both as to organization and method of operation, may best be understood by reference to the detailed description which follows taken in conjunction with the accompanying drawings in which:

Figure 1A, is a cross-sectional view of a base of a VMD having an conductive layer over an insulative substrate.

Figure 1B, is a cross-sectional view of another embodiment of a base of a VMD having an conductive

layer, and an in insulator layer over a conductive substrate.

Figure 2, show a cross-sectional view of the base of Figure 1A having a grid insulator and a grid conductor over it.

Figure 3, is a cross-sectional view with a portion of the VMD structure etched.

Figure 4, is a cross-sectional view showing the deposition of a cusp forming material.

Figure 5, is a cross-sectional view showing the deposition of an electron-emitting material.

Figure 6, is a cross-sectional view showing the access holes through the electron-emitting material.

Figure 7A, is a cross-sectional view of a completed VMD triode as a result of an isotropic etching.

Figure 7B, is a cross-sectional view of a VMD triode as a result of an anisotropic etching.

Figure 8, is a cross-sectional view of a completed VMD triode as a result of an isotropic etching of the structure of Figure 7B.

Figure 9A, is a cross-sectional view of VMD diode made according to the teachings of this invention.

Figure 9B, is a cross-sectional view of another embodiment of a VMD diode made according to the teachings of this invention.

Figure 9C, is a cross-sectional view of still another embodiment of a VMD diode made according to the teachings of this invention.

Figure 9D, is a cross-sectional view of yet still another embodiment of a VMD diode made according to the teachings of this invention.

Figure 10, is a cross-sectional view of a completed pentode VMD made according to the teachings

of this invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention describes a novel new technique and structure for the integrated fabrication of one or more integrated Vacuum Microelectronic Devices.

One of the major elements in the fabrication of the integrated Vacuum Microelectronic Device is the use of the cusp which is formed by the conformal deposition in a round hole. Other symmetrical hole shapes will also result in a single pointed cusp, but a round shaped hole will result in an optimum cusp.

The layer made of conductive material could also be made of composite layers of conductive material, so that the tip ends up as being made of a layered or composite material.

Once this template is etched away using isotropic etch which simultaneously forms the vacuum space, an emitter point will result. Preferably, this tip should have the required small radius (for example between 10-100nm), required by the device, but if necessary, the tip can be further sharpened by isotropic etching or oxidizing a small amount of the conductor tip to achieve any desired tip radius.

It is important to note that many different combinations of materials, deposition techniques (sputter, CVD, plating, etc.), and etch techniques (wet, dry, ion, etc.) or additive pattern formation techniques can be used in the fabrication steps.

Another method of vertical integration is the stacking of whole device layer sets one on top of another. Since these devices are not dependent on special materials such as single crystal silicon,

these device layer sets can also be integrated on top of other technologies such as semiconductors and multilayer ceramic packages.

The detailed description of the Vacuum Microelectronic Device structure and the process for fabricating it, as described below, has been simplified by using several predefined and named process sequences or definitions that are repetitively referenced.

The term VMD or Vacuum Microelectronic Device as used herein, means not only a diode but a triode, tetrode, pentode or any other device that is made using this process, including the interconnection thereof. Basically, a VMD is any device with at least a sharp emitter (cathode) tip, and a collector (anode) with an insulator separating the emitter and there is a preferably a direct transmission of electrons from the emitter to the collector.

The term "lithographically defined" refers to a process sequence of the following process steps. First a masking layer that is sensitive in a positive or negative sense to some form of actinic radiation, for example, light, E-beams, and/or X-rays, is deposited on the surface of interest. Second, this layer is exposed patternwise to the appropriate actinic radiation and developed to selectively remove the masking layer and expose the underlying surface in the patterns required. Third the exposed surface is etched to remove all or part of the underlying material as required. Fourth, the remaining areas of the masking layer are removed.

Alternatively, the term "lithographically defined" can refer to following "liftoff process." The same required patterns in a material layer as produced in the previously described process are

created. This process starts on the surface that is to receive the desired patterned material layer. First, a masking layer that is sensitive in a positive or negative sense to some actinic radiation, for example, light, E-beams, and/or X-rays, is deposited on the surface. Secondly, this layer is exposed patternwise to the appropriate actinic radiation and developed to selectively remove the masking layer and expose the underlying surface in patterns where the desired material layer is to remain. The deposition, exposure, and development process is controlled in such a way that the edges of the remaining mask image has a negative or undercut profile. Thirdly, the desired material is deposited over both the open and mask covered areas by a line of sight deposition process such as evaporation. Finally, the mask material is removed, for example, by dissolution and freeing any material over it and allowing it to be washed away.

The term "conductive material" or "conductor layer" or "conductive substrate" refers to any of a wide variety of materials which are electrical conductors. Typical examples include the elements Mo, W, Ta, Re, Pt, Au, Ag, Al, Cu, Nb, Ni, Cr, Ti, Zr, and Hf, alloys or solid solutions containing two or more of these elements, doped and undoped semiconductors such as Si, Ge, or those commonly known as III-V compounds, and non-semiconducting compounds such as various nitrides, borides, cubides (for example LaB_6), and some oxides (of for example Sn, Ag, InSn).

The term "insulative material" or "insulator layer" or "insulative substrate" refers to a wide variety of of materials that are electrical insulators especially glasses, and ceramics. Typical

examples include elements such as carbon in a diamond form (crystalline or amorphous), single crystal compounds such as sapphire, glasses and polycrystalline or amorphous compounds such as some oxides of Si, Al, Mg, and Ce, some fluorides of Ca, and Mg, some carbides and nitrides of silicon, and ceramics such as alumina or glass ceramic.

The term "electron-emitting material" or "emitter layer" or "emitter material" refers to any material capable of emitting electrons under the influence of an electric field. Typical examples include any of the electrical conductors, such as the examples listed above, and borides of the rare earth elements, solid solutions consisting of 1) a boride of a rare earth or an alkaline earth (such as Ca, Sr, or Ba), and 2) a boride of a transition metal (such as Hf or Zr). The emitter material can be a single layered, a composite or a multilayered structure. An example of a multilayered emitter might include, the addition of one or more of the following, a work function enhancement layer, an robust emitter layer, a sputter resistant layer, a high performance electrically conductive layer, a thermally conductive layer, a physically strengthening layer or a stiffening layer. This multilayered composite may contain both emitter and non-emitter materials, which can all act synergistically together to optimize emitter performance. An example of this is discussed in Busta, H. H. et al. "Field Emission from Tungsten-Clad Silicon Pyramids", IEEE Transactions on Electron Devices, Vol. 36, No. 11, pages 2679-2685 (November 1989), where they show the use of coating or cladding on these cathode tips or pyramids to enhance or modify the cathode tip properties.

This coating or cladding can also be used in

situations where one cannot form the desired tip structure or it is difficult to form the desired tip structure for the cathode emitter.

The term "deposited" refers to any method of layer formation that is suitable to the material as are generally practiced throughout the semiconductor industry. One or more of the following examples of deposition techniques can be used with the previously mentioned materials, such as, sputtering, chemical vapor deposition, electro or electroless plating, oxidation, evaporation, sublimation, plasma deposition, anodization, anodic deposition, molecular beam deposition or photodeposition.

The term "tip" as used herein means not only a pointed projection but also a blade. Field emitter shapes other than points are sometimes used, such as blades. Blades are formed using the same methods except that the hole is a narrow elongated segment. The shape of the sharp edge of the blade can be linear or circular or a linear segment or a curved segment to name a few.

The hole that is used to eventually form the cusp, from the cusp forming material, can be formed by a process selected from a group comprising, ablation, drilling, etching, ion milling or molding. The hole can also be etched, using etching techniques selected from a group comprising anisotropic etching, ion beam etching, isotropic etching, reactive ion etching, plasma etching or wet etching. The hole could have a profile where the dimensions of the hole are constant with depth or the dimensions of the hole could vary with depth.

The cusp forming material is preferably conformally deposited. The cusp forming material could be an insulative material or it could comprise

of multilayers.

The access hole that is formed to remove the material from underneath the electron-emitter tip could be formed by a process selected from a group comprising, ablation, drilling, etching or ion milling. The access hole could also be etched, using etching techniques selected from a group comprising anisotropic etching, ion beam etching, isotropic etching, reactive ion etching, plasma etching or wet etching. Similarly, the material under the cusp could be removed by a process selected from the group comprising, dissolution or etching.

The substrate may be an insulator and serve as part of the isolation between adjacent electrical structures. Insulating substrates are especially useful in minimizing parasitic capacitance which can in turn significantly improve device frequency response. Transparent insulating substrates are especially useful in display applications where the substrate can also serve as the display window on which both light emitting structures and control circuits can be integrated together.

The substrate could be made of a conductive material. A conductive substrate may serve as part of the functioning structure such as a common anode (plate) or a common bias voltage conductor. A conductive substrate can also be isolated from the electrical devices with the simple addition of an insulating layer.

The substrate whether made from a conductive material or an insulative material serves primarily as a physical support for subsequent functional layers and processing.

Figures 1A and 1B, illustrate the device base structure. If the Vacuum Microelectronic Device, is

to be formed on an insulative substrate 10, then a film or layer of conductive anode 13, is deposited directly on the insulative substrate 10, as illustrated in Figure 1A. The insulative substrate 10, could be made of a silicon dioxide material, but other materials as discussed earlier can be used. Doped polysilicon is a typical material for the anode 13, but other electrically conductive material as discussed elsewhere could be used.

When a conductive substrate is used as a common anode, or is a doped semiconductor material with any desired isolations formed by electrically biased P-N junctions, that substrate can be used directly. If, a non-semiconductor conductive substrate (or a doped semiconductor substrate without P-N junctions), is to be isolated from the electrical devices, then an insulating layer is deposited, followed by the deposition of an anode conductive layer.

If an electrically isolatable VMD device is to be formed on conductive substrate 11, as shown in Figure 1B, then on the conductive substrate 11, an insulative film or layer 12 is deposited. A layer or film of a conductive anode 13, which could be doped polysilicon, is then deposited on the insulator layer 12. The material for the conductive substrate 11, could be a silicon material. The insulative layer 12, can be formed by the oxidizing the silicon material of the substrate 11, or be deposited by other means known in the art. Other materials that are equally acceptable for the conductive substrate 11 or the insulative layer 12, have already been discussed earlier.

Once it is decided on the basic substrate structure then the subsequent steps can be the same. For the illustration of the best mode to carry out

this invention the substrate configuration of Figure 1A, will be used, even though similar device would result if the substrate configuration of Figure 1B, is used.

As shown in Figure 2, on the anode conductive layer 13, a layer of grid insulator 15, could be made for example, by oxidizing the doped polysilicon of layer 13, or by depositing an insulating glass layer, to name a few. On top of grid insulator 15, is deposited a layer of grid conductor 17, by any of the methods discussed earlier. The material for the grid conductor 17, for example, could be doped polysilicon but, other materials discussed elsewhere can also be used.

This process of forming additional insulative or conductive materials is repeated for each control electrode structure desired in the final active device.

The next step is to create the vacuum hole or space 19, as shown in Figure 3. The vacuum space 19, is lithographically defined and etched by methods well known in the art. The shape of the etch vacuum space 19, can be square, round, oval, etc. The radius or half of the maximum cross-sectional width of the etched vacuum space 19, should be smaller than the thickness of the sum of the layers that are deposited or formed above the anode grid conductor 17. Anisotropic reactive ion etching RIE (Reactive Ion Etching) is the preferred etch method, but other methods known in the art could also be used. The vertical or near vertical hole walls have minimal lateral etching. This keeps electrode holes small and uniform and also minimizes the overall area occupied by the device. This operation creates holes through all of the control electrode conductor and

insulator layers and will ultimately provide the vacuum spaces for each of the Vacuum Microelectronic Devices. Etching is continued through the grid conductive layer 17, and the grid insulator layer 15, until at least a portion of the anode layer 13, is exposed. The vacuum space 19, does not need to extend all the way to the upper surface of the conductive material or anode 13, if any of the left-over material of the grid material or insulator 15, will etch out in the subsequent vacuum space etching. It should be noted that the base layer or substrate that is used be of sufficient thickness to allow for the proper formation of hole or vacuum space 19.

As shown in Figure 4, an insulative layer 21, of sufficient thickness is conformally deposited to close the etch vacuum space 19, in Figure 3, and form a cusp 23. The insulative layer 21, for the purpose of illustration is a silicon dioxide material. The insulative layer 21, can be formed, for example, by conformal chemical vapor deposition (CVD) process. Conformal CVD deposition is typically used but other processes such as anodization, and even marginally conformal processes such as sputtering can produce acceptable results. Deposition is continued until the sidewall coatings converge and close the vacuum space hole 19. This convergence forms the symmetrical cusp 23, with a very fine convergence point at the bottom which is self-aligned to the center of the vacuum space hole 19.

An electron-emitting material or layer 25, is deposited by any means that will allow the material to fill the cusp 23. This deposition could be done as shown in Figure 5, for example, by CVD, evaporation, sublimation, sputtering, electroless

deposition, or plating. The electron-emitting layer 25, acts as a cathode during the operation of the device, and the sharp tip 27, acts as the cathode emitter. The electron-emitting material 25, could be formed for example by using doped polysilicon or tungsten, but other materials as discussed elsewhere could also be used.

The emitter layer 25, is now lithographically featured with one or more access holes 29 and 30, exposing the insulator layer 21, as shown in Figure 6. Two or more holes per device are desirable to improve etching access, and to control undercut as will be explained below. The access hole(s) are positioned to overlap the vacuum space hole 19, partially but not to overlap the cusp 23.

The insulator layer 21, is now selectively etched completely out of the vacuum space 19, leaving conductive layers 25, 17 and 13, intact. This leaves a bridge 37, of emitter layer 25, spanning the newly created vacuum space or hole or chamber 39, and supporting the sharp emitter tip 27, above the exposed anode 13. The selective etch can etch grid insulator 15, without harm to the finished device. The selective etch can be a single step isotropic (wet or plasma) etch which will result in a finished device 45, as shown in Fig. 7A.

Device 45 in Fig. 7A is a functionally acceptable triode device with emitter tip 27, self-aligned in grid electrode 17, and directly opposed to anode 13. It does, however, exhibit excessive nonfunctional undercut 40, which not only weakens the device structure, but also enlarges the device and adversely affects the circuit density.

A two-step etch process minimizes these unnecessary attributes. A selective anisotropic etch

is first used to etch, without undercut, layer 21, all the way to the bottom of the vacuum hole 19, as shown in Fig. 7B. This is possible because the access holes 29 and 30, overlap the vacuum space or hole 19. This leaves only a thin partition or a web 31, under the emitter bridge 37, when two access holes 29 and 30, one on each side of the bridge 37, are used. A selective isotropic etch (wet or plasma) is then used to remove the insulator partition 31, from under the bridge 37, freeing the sharp emitter tip 27, and completing the opening of vacuum space or chamber 39, as shown in Figure 8. The resulting undercut 41, on other exposed insulator edges, is limited to an amount equal to half the thickness of partition 31, because it is being etched from both sides. The resulting finished device 50, is shown in Fig. 8.

It must be remembered that the access holes 29 and 30, as shown in Figure 7B, are in two dimensions, and that the etching to create access holes 29 and 30, was carried out using isolated holes, and therefore both the partitions 31 and bridge 37, are still a part of the insulating layer 21 and the conductive layer 25, respectively.

The removal of the material under the bridge 37, is usually the last operation done in order to minimize contamination of that space or to avoid the problem of removing future processing materials from that confined area.

The sharp emitter tip 27, molded by the cusp 23, can generally be controlled to have the desired small radius tip without requiring further processing. If, however, a smaller tip radius is desired or if a particular set of desirable materials, process techniques, and/or process conditions produce a

larger then desired tip radius, then the tip can be sharpened. This sharpening (the reduction of the tip radius) can be done, for example, by slow etching of the tip with an isotropic etch or the oxidation of the tip followed by the removal of the oxide layer.

The process above, which results in triode Vacuum Microelectronic Device 45 or 50, can easily be adapted to form other configurations. In the figures for the following examples the two step etch process as used to remove layer 21, from hole 19, to create vacuum space 39, as was used to produce triode device 50, will be illustrated.

Figures 9A, 9B, 9C, and 9D, illustrate a few embodiments of a diode made according to the teachings of this invention. An example of a diode process sequence is created starting with the basic triode process sequence through grid insulator 15. The grid conductor layer 17, is eliminated. The remaining process steps that would normally produce triode 50, will now produce VMD diode 60, illustrated in Fig. 9A. The phantom boundary of vacuum space hole 19, would be solid if the selective etch for the conformal layer 21, does not attack layer 15, or would be lost as shown if it is attacked by the selective etch process.

Figure 9B, shows the simplest form of a diode structure that can be made by etching a vacuum hole 79, which is similar to the hole 19, directly into a conductive substrate 11. The layer 11, must be sufficiently thick to allow for the formation of the hole 79. Starting with the deposition of the conformal layer 21, the processing continues as discussed earlier. A VMD diode 65, will result once the process is completed as illustrated in Fig. 9B.

Similarly, a diode structure that can be

produced on an insulative substrate 10, which has been covered with the anode layer 13, is disclosed in Figure 9C. The layer 13, must be sufficiently thick to allow for the formation of the hole 79, which is similar to the hole 19. The processing continues as discussed earlier and upon completion, the result is a VMD diode 70, as shown in Fig 9C.

Another embodiment of this invention is illustrated in Figure 9D, where the insulative substrate 10, is first featured with hole 79, and then anode conductive material or layer 86, is conformally deposited. The basic process starting with the conformal deposition of insulator layer 21, as discussed earlier is followed and the end result is a VMD diode 75, as illustrated in Fig. 9D.

Many variations of more complex Vacuum Microelectronic Devices can also be created by extending the basic triode process. One example of this variation is a VMD pentode device 90, as shown in Fig. 10. The device 90, can be created from the basic triode process sequence by following the basic triode device sequence through the deposition of grid conductor layer 17, then adding steps depositing grid insulator 93, on grid conductor 17, depositing grid conductor layer 94, on layer 93, depositing grid insulator layer 95, on layer 94, and depositing grid conductor layer 96, on layer 95. The basic triode process is resumed at this step by creating hole 19. In this case the hole 19, is etched through all the layers until the upper surface of the conductive material or layer 13, is exposed. If the basic triode process sequence that would normally lead to device 50, is followed from this point, it will result in pentode device 90.

The insulator and conductor layers used above to

create the Vacuum Microelectronic Devices described can also be used to isolate and interconnect multiple electronic devices or components in three dimensions, integrating circuits of these devices at the same time that the devices are being fabricated. This is not illustrated but can be accomplished by lithographically patterning each conductive and insulative layer after it is deposited and before proceeding to the next step. Conductor material is removed where isolations are desired and featured into islands and paths to form interconnections between different devices, between devices and vias, and between different vias. Insulator layers can be featured with a pattern of via openings to the conductive layer below. Actual via connections may be made either by the formation of a stud (a conductive plug formed by a number of conventional methods) or filled by the direct blanket deposition of the next conductive layer thus creating vertical interconnection pathways through the structure.

Any interconnection patterns created on the emitter level can be made at the same time that the access holes 29 and 30, are being made, but since the insulator under them will be etched when the vacuum space is etched the undercutting of these interconnections represents a limitation on the size of these features. The two step etch will significantly minimize this undercut just as it does in the device itself, but a further enhancement of this process can eliminate undercut everywhere except the vacuum device area. To accomplish this, a separate or a second lithographic step is used to feature any emitter level isolations interconnections and access holes. The second lithographic patterning protects all of the interconnection and isolation

features and exposes only the access holes. The vacuum space etching which follows uses the two step etch previously described and the small amount of undercut that occurs is limited to the vacuum space area only.

Many combinations of insulators and conductors may be used in the fabrication procedures and device structures described. Specific applications may dictate special material properties such as resistivity, dielectric constant, thermal stability, physical strength, etc. but in general there are three basic requirements for compatibility. First, the materials must be compatible with the processing required for fabrication which may limit some material combinations in particular fabrication regimes. Second, their must be adequate adhesion between adjacent layers. Third, the materials must be stable and not contaminate the operating environment of the vacuum devices which is typically a moderate to high vacuum. This last requirement is somewhat open because some of these devices may be able to operate in up to 1 atmosphere or more of a high ionization potential gas such as He. This may be possible because their microscopic dimensions provide very small path lengths and allow the use of low extraction voltages.

While the present invention has been particularly described, in conjunction with a specific preferred embodiment, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. It is therefore contemplated that the appended claims will embrace any such alternatives, modifications and variations as falling within the true scope and spirit of the

present invention.

WHAT IS CLAIMED IS:

1. A process of making at least one integrated vacuum microelectronic device comprising the steps of:

a) providing at least one hole in a substrate having at least one electrically conductive material,

b) filling at least a portion of said hole with at least one material sufficiently to form a cusp,

c) depositing at least one layer of a material which is capable of emitting electrons under the influence of an electrical field, and filling at least a portion of said cusp to form a tip,

d) providing at least one access hole to help facilitate the removal of material underneath the cusp, and

e) removing the material underneath said cusp to expose at least a portion of said tip of said electron-emitting material and at least a portion of said electrically conductive material in said substrate, thereby forming said at least one integrated vacuum microelectronic device.

2. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said substrate comprises of at least one insulative layer, and wherein said insulative layer separates said electrically conductive material from said

electron-emitting material.

3. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said substrate comprises of a multilayered structure.

4. The process of making an integrated vacuum microelectronic device of Claim 3, wherein said multi-layered structure comprises of alternating layers of insulative and electrically conductive material.

5. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said hole in step (a) is formed by a process selected from a group comprising, ablation, drilling, etching, ion milling, lift-off or molding.

6. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said hole in step (a) is etched, using etching techniques selected from a group comprising anisotropic etching, ion beam etching, isotropic etching, reactive ion etching, plasma etching or wet etching.

7. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said hole has a profile where the dimensions of the hole are constant with depth.

8. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said hole has a profile where the dimensions of the hole varies with depth.

9. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said cusp forming material is conformally deposited.

10. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said cusp forming material is an insulative material.

11. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said cusp forming material comprises of multilayers.

12. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said electron-emitting material is a single layered material.

13. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said electron-emitting material is multilayered.

14. The process of making an integrated vacuum microelectronic device of Claim 1, wherein in step (d) said access hole is formed by a process selected from a group comprising, ablation, drilling, etching, lift-off or ion milling.

15. The process of making an integrated vacuum microelectronic device of Claim 1, wherein in step (d) said access hole is etched, using etching techniques selected from a group comprising anisotropic etching, ion beam etching, isotropic etching, reactive ion etching, plasma etching or wet etching.

16. The process of making an integrated vacuum microelectronic device of Claim 1, wherein in step (e) said material under the cusp is removed by a process selected from the group comprising, dissolution or etching.

17. The process of making an integrated vacuum microelectronic device of Claim 1, wherein a barrier layer is formed prior to the deposition of said electron-emitting material.

18. The process of making an integrated vacuum microelectronic device of Claim 17, wherein said barrier layer is selectively removed.

19. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said tip is coated with an electron-emitting material.

20. The process of making an integrated vacuum microelectronic device of Claim 1, wherein said tip is selectively sharpened by a process selected from a group comprising slow isotropic etching or oxidation.

21. A process of making at least one integrated vacuum microelectronic device comprising the steps of:

a) providing at least one hole in a substrate,

b) depositing at least one insulative material and filling said hole to form a cusp,

c) depositing at least one layer of a material which is capable of emitting electrons under the influence of an electrical field, and filling at least a portion of said cusp to form a tip,

d) providing at least one access hole to help facilitate the removal of material underneath the cusp, and

e) through said access hole removing all of said material in said hole and exposing at least a portion of said tip of said electron-emitting material and at least a portion of said electrically conductive material in said substrate, thereby forming said at least one integrated vacuum

microelectronic device.

22. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of a conductive material.

23. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of a conductive material over an insulative material such that said conductive material is thick enough to contain said hole.

24. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of two insulating materials separated by a conductive material, wherein one of said insulting material is thick enough to form said hole and wherein said hole exposes at least a portion of said conductive material.

25. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of an insulative material which is thick enough to form said hole, and wherein said conductive material is conformally deposited in said hole prior to the deposition of said insulative material of step (b).

26. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said

substrate comprises of at least two conductive materials separated by at least one insulative material and wherein said hole penetrates one conductive material one insulative material and exposes at least a portion of a second conductive material.

27. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of an insulative base material and having least two conductive materials separated by at least one insulative material and wherein said hole penetrates one conductive material one insulative material and exposes at least a portion of a second conductive material.

28. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of a conductive base material and further having a plurality of electrically conductive material over said substrate, such that each said electrically conductive material is separated by an insulative material, wherein said hole penetrates all of said conductive materials and said insulative material and exposes at least a portion of said base conductive material.

29. The process of making an integrated vacuum microelectronic device of Claim 21, wherein said substrate comprises of a conductive base material over an insulative base material and further having a plurality of electrically conductive material over

said substrate, such that each said electrically conductive material is separated by an insulative material, wherein said hole penetrates all of said conductive materials and said insulative material and exposes at least a portion of said base conductive material.

30. An integrated vacuum microelectronic device comprising an electron-emitting material having a field emission tip and at least one access hole that leads into a chamber, wherein said field emitter tip faces an anode which is in said chamber and is separated by at least one material.

31. The integrated vacuum microelectronic device of Claim 30, wherein said material is an insulating material.

32. The integrated vacuum microelectronic device of Claim 30, wherein said material has two or more insulating materials separated by at least one electrically conductive material.

33. The integrated vacuum microelectronic device of Claim 30, wherein said electron-emitting layer is multilayered.

34. The integrated vacuum microelectronic device of Claim 30, wherein at least one tip of said electron-emitting layer is multilayered.

35. The integrated vacuum microelectronic device of Claim 30, further comprising on the tip side of the electron-emitting layer at least one barrier layer, which is selectively removed to expose said tip.

36. The integrated vacuum microelectronic device of Claim 30, wherein said tip has a coating of an electron-emitting material.

37. The integrated vacuum microelectronic device of Claim 30, wherein said tip is sharpened.

38. The integrated vacuum microelectronic device of Claim 30, wherein at least one tip is electrically isolated from another tip.

39. The integrated vacuum microelectronic device of Claim 30, wherein at least one tip is electrically connected to another electronic component.

40. The integrated vacuum microelectronic device of Claim 30, wherein said anode is part of an electronic display device.

41. The integrated vacuum microelectronic device of Claim 30, wherein said device is used in an electronic display device.

42. The integrated vacuum microelectronic device of Claim 30, wherein said tip has a point or a blade profile.

43. The product made by the process of Claim 1.

44. The product made by the process of Claim 21.

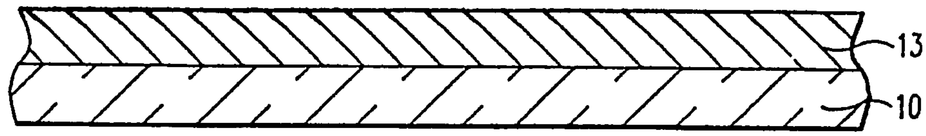

FIG. 1A

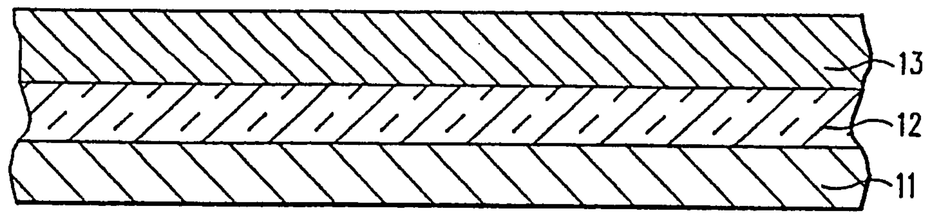

FIG. 1B

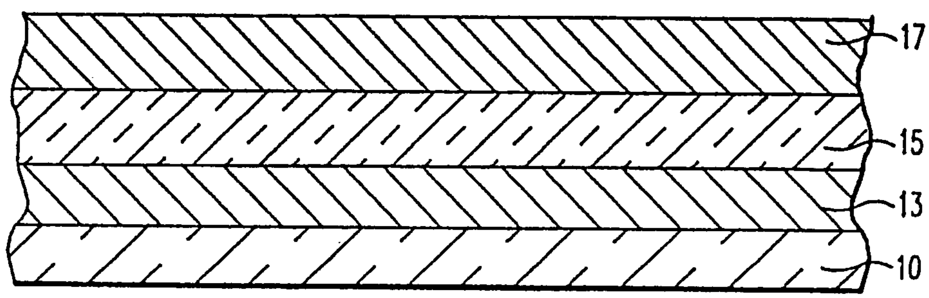

FIG. 2

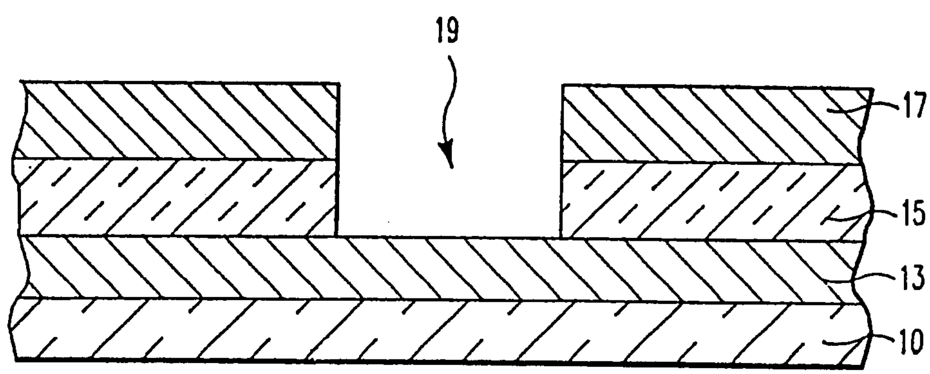

FIG. 3

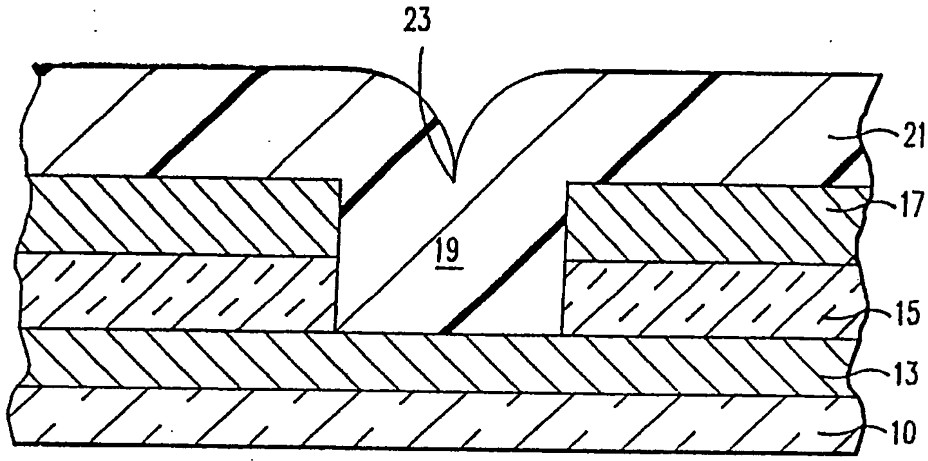

FIG. 4

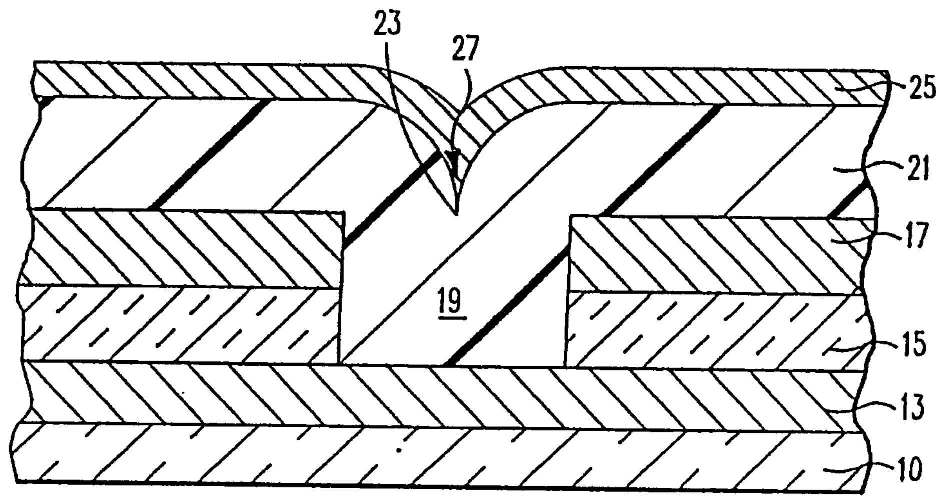

FIG. 5

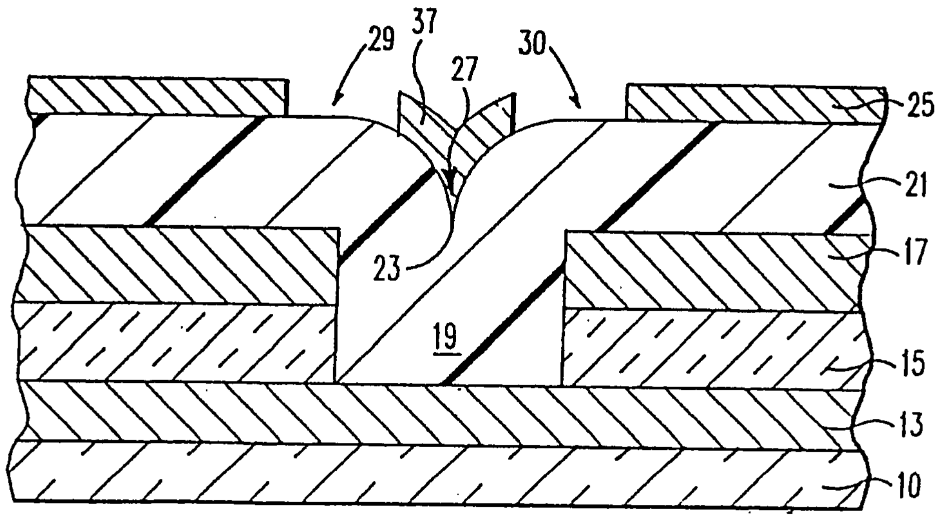

FIG. 6

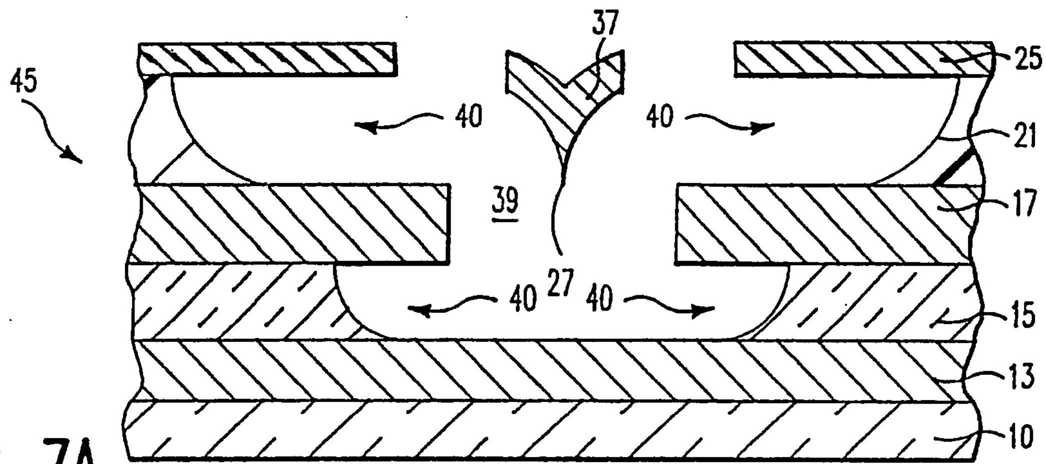

FIG. 7A

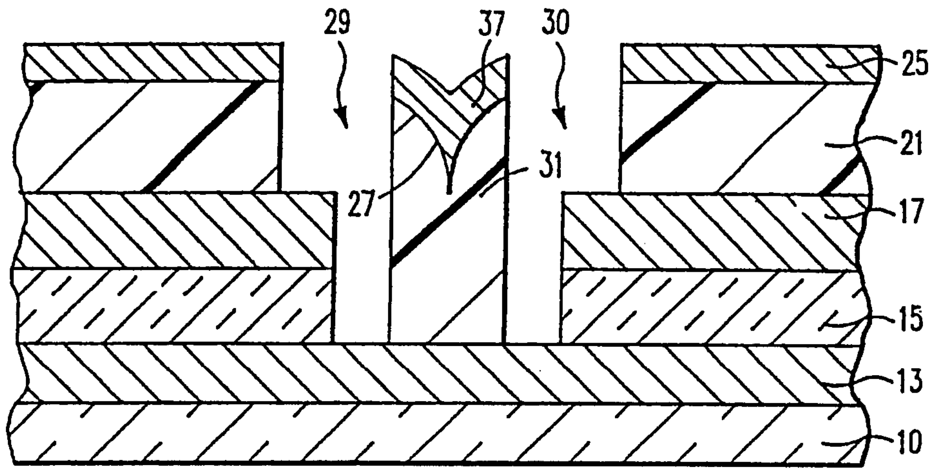

FIG. 7B

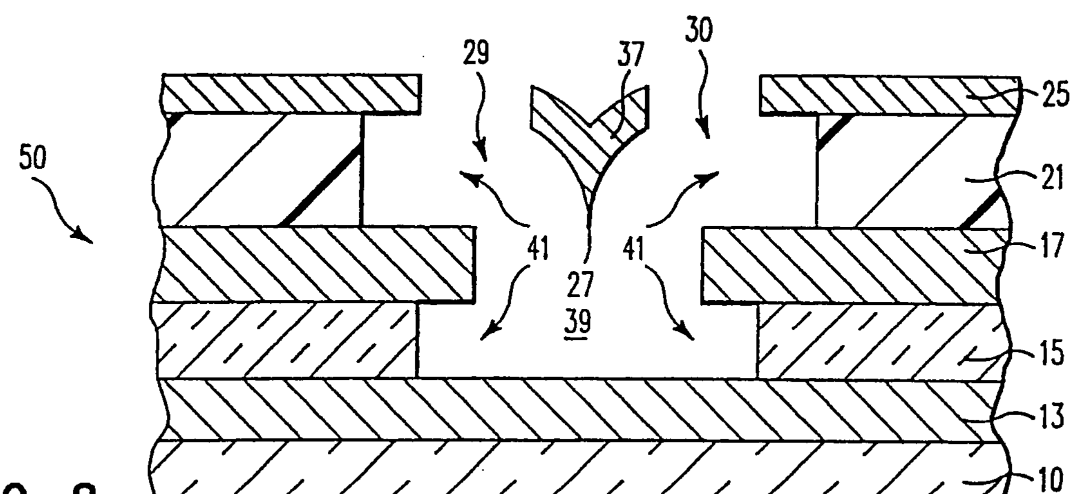

FIG. 8

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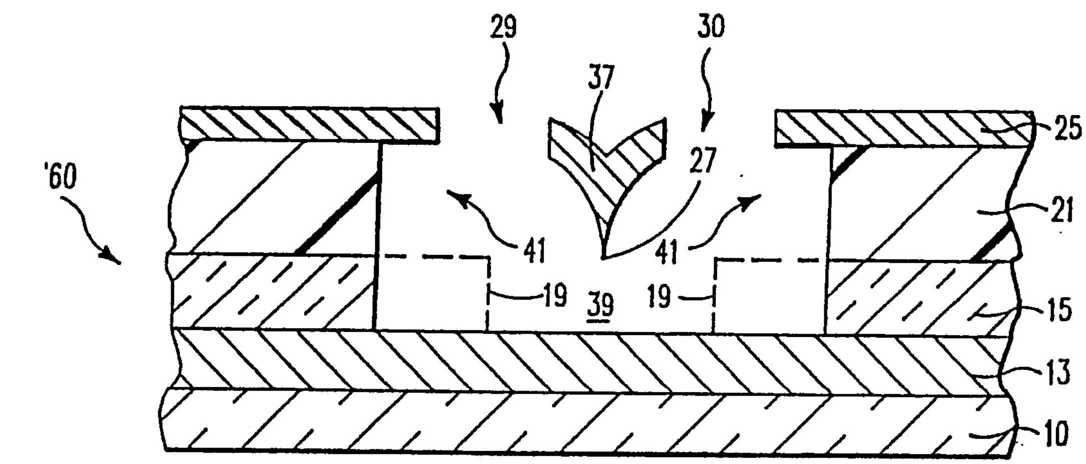

FIG. 9A

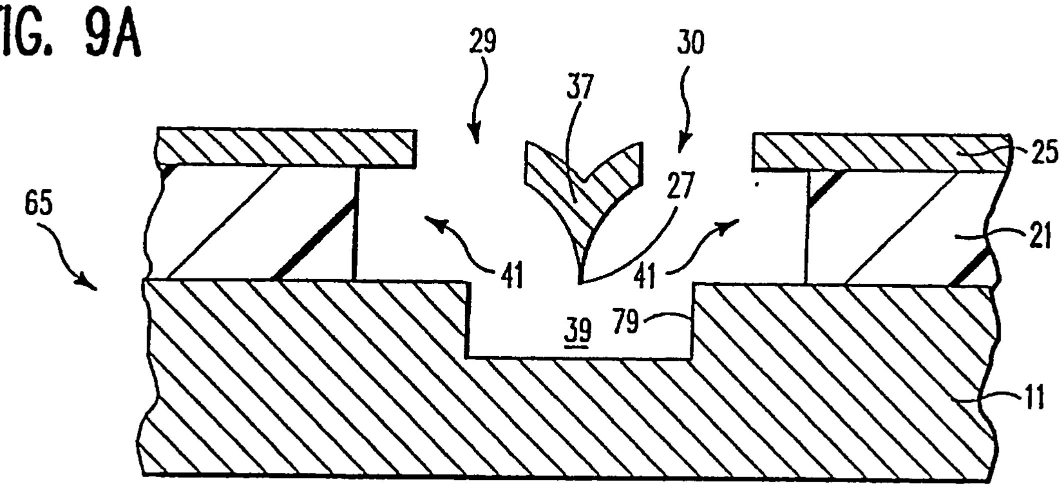

FIG. 9B

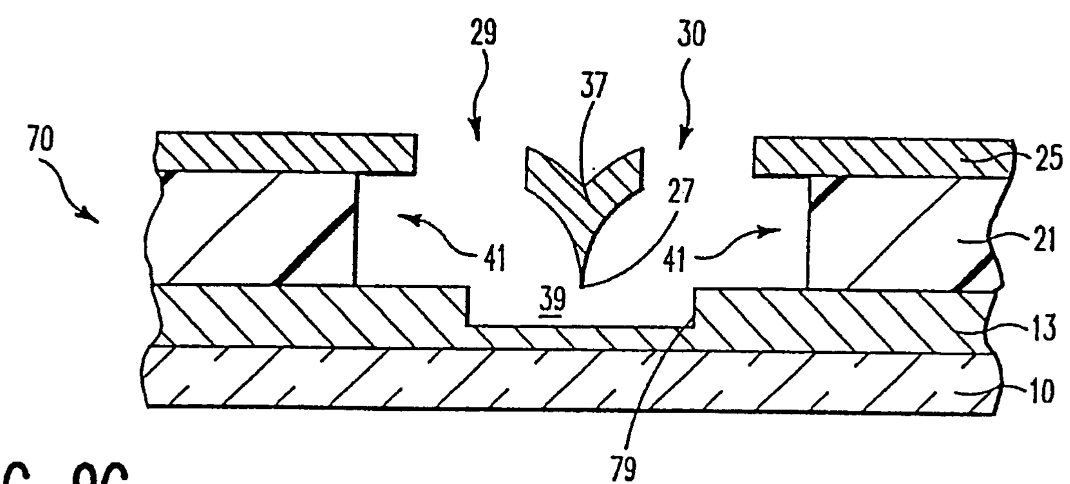

FIG. 9C

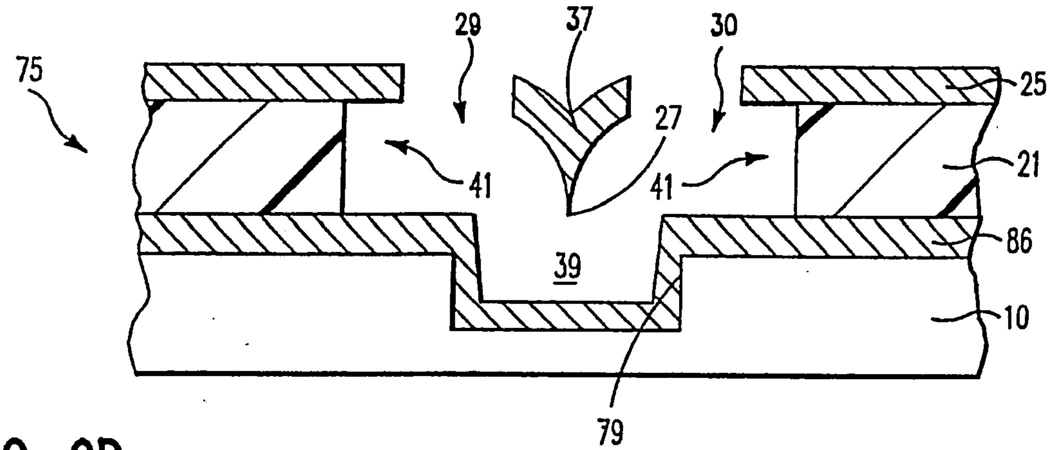
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FIG. 9D

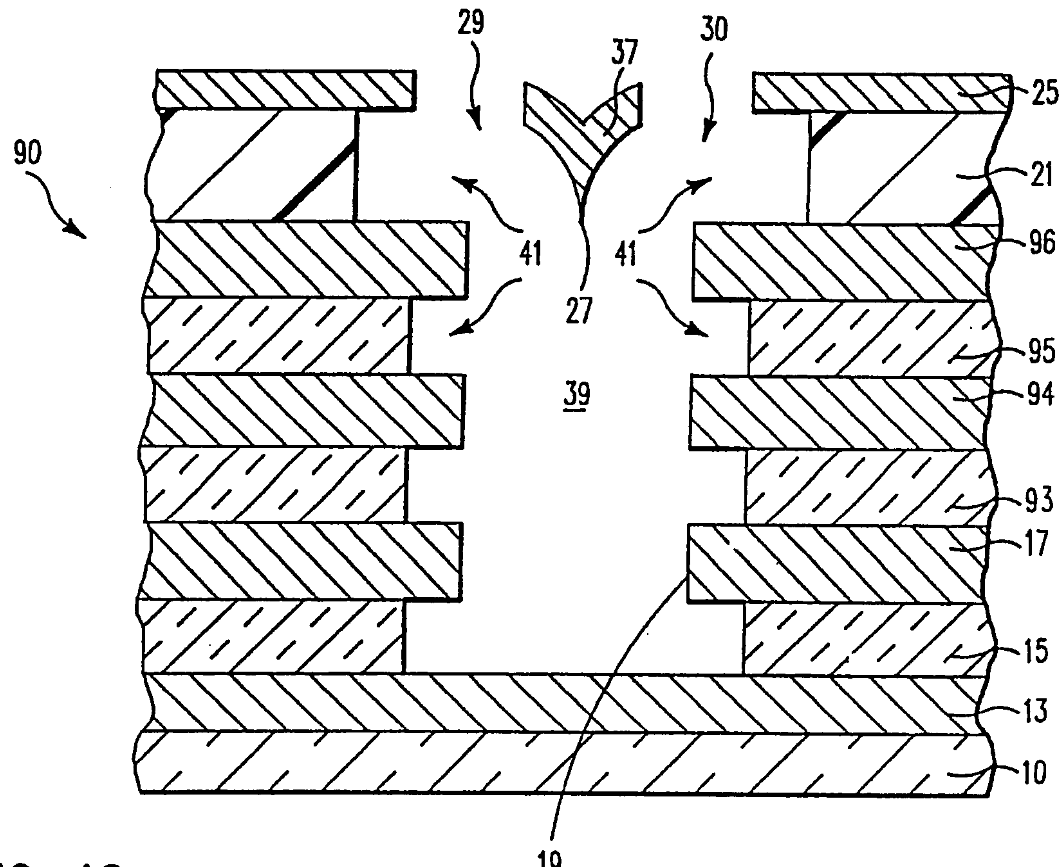
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FIG. 10

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/05963

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: H 01 J 1/30, 9/02

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	H 01 J

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	US, A, 4721885 (I. BRODIE) 26 January 1988, Cited in the application --	1-44
A	IEEE TRANSACTIONS ON ELECTRON DEVICES, Vol. 36, No. 11, November 1989, I BRODIE: "Physical Considerations in Vacuum Microelectronics Devices ", see page 2641 - page 2644 Cited in the application --	1-44
A	C.A. SPINDT"A Thin-Film Field-Emission Cathode", 1968, Stanford Research Institute, California, see page 3504- page 3505 --	1-44

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
5th March 1991	22.03.91
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	F.W. HECK

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	US, A, 3755704 (SPINDT ET AL) 28 August 1973, Cited in the application --	1-44
A	US, A, 3665241 (SPINDT ET AL) 23 May 1972, Cited in the application --	1-44
A	IEEE TRANSACTIONS ON ELECTRON DEVICES, Vol. 36, No. 11, November 1989, N.A. CADE ET AL: "Wet Etching of Cusp Structures for Field-Emission Devices ", see page 2709 - page 2714 Cited in the application --	1-44
A	US, A, 3998678 (S. FUKASE ET AL) 21 December 1976, Cited in the application --	1-44
A	US, A, 3970887 (D. O. SMITH ET AL) 20 July 1976, Cited in the application --	1-44
A	US, A, 4307507 (H.F. GRAY ET AL) 29 December 1981, Cited in the application --	1-44
A	MAT. RES. SOC. SYMO. PROC., Vol. 76, 1987,(WASHINGTON) G.J. CAMPISI ET AL: "MICROFABRICATION OF FIELD EMISSION DEVICES FOR VACUUM INTEGRATED CIRCUITS USING ORIENTATION DEPENDENT ETCHING ", see page 67 - page 72 Cited in the application --	1-44
A	US, A, 3921022 (J.D. LEVINE) 18 November 1975, Cited in the application --	1-44

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	INTERNATIONAL ELECTRON DEVISES MEETING, Vol., 1989,(WASHINGTON) W.J. ORVIS ET AL: "A PROGRESS REPORT ON THE LIVERMORE MINIATURE VACUUM TUBE PROJECT ", see page 529- - page 531 Cited in the application --	1-44
A	IEEE TRANSACTIONS ON ELECTRON DEVICES, Vol. 36, No. 11, November 1989, H.H. BUSTA ET AL: "Field Emission from Tungsten-Clad Silicon Pyramids ", see page 2679 - page 2685 Cited in the application --	1-44
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